Poznań, 17.07.2023

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Review of the doctoral thesis of Mahmoud Hamed entitled „Dust Attenuation in Dusty Star-Forming Galaxies Using Spectral Energy Distribution"

Summary of the thesis

Modelling of spectral energy distribution (SED) of galaxies is one of the main tool in the investigation of galaxy evolution. This thesis addresses the question of attenuation curves, a key component which needs to be implemented in such studies.

Chapter 2 presents the analysis of the spectral energy distribution and the carbon monoxide (CO) line of a pair of galaxies, a dusty one and a blue one at $z \sim 2$. The conclusion is that one of the galaxies is quenching.

Chapter 3 describes the measurement of the attenuation curves that best fit the data for 122 galaxies at redshifts $1 < z < 4$ detected by ALMA. The correlations between the slope of the attenuation curve and stellar-to-dust emission size ratio, the attenuation strength, and star formation rate are explored.

Chapter 3 focuses on a thousand of galaxies at redshifts $0.5 < z < 0.8$, placed on the diagram with infrared excess (IRX, the ratio of the infrared and ultraviolet luminosities) and slope of the ultraviolet continuum (β). The position on this diagram is found to be driven by metallicity and Sersic index. The correlations with stellar mass, specific star formation rate, specific dust mass, age, disk orientation, and environment are explored.

Contribution to the field

The main important results includes the correlation between the steepness of the attenuation curve and stellar-to-dust emission size ratio (Fig. 3.12), gas metallicity (Fig. 4.6), age, stellar mass, specific star formation rate and Sersic index (Fig. 4.7), presented in chapters 3 and 4. This presents the interplay between stellar emission and dust, and can inform the attenuation law appropriate for a given galaxy.

The implications of chapter 2 are limited, because this is a study of a single system. However, this demonstrates how one can learn about the nature of galaxies from broad-band and CO data.

Below I point out the weaknesses of this thesis with the aim of helping to improve the future work.

Generalisation of the attenuation curve slope trends

It would strengthen the work to add several general aspects to the characterisation of the attenuation curve slopes. First, in chapter 3 a more general form of the attenuation curve could be used with the slope as a free parameter. This would improve the current study based on three separate parametrisations.

Second, the connection between the IRX-β plot and attenuation curves could be investigated in more details in chapter 4. For example the trends for steep and shallow attenuation curves could be shown on this diagram. Moreover, it could be checked if the SED-derived attenuation curve (as in chapter 3) correlates with the position on the IRX-β diagram.

Third, several correlations on the IRX-β diagram were found (Fig. 4.6 and 4.7). It would be great to statistically test which of these parameters is the main driver of the position on this diagram and which are just secondary correlations. For example if the metallicity is the main determinant, then the correlation with stellar mass is only the result of the mass-metallicity relation. However, the importance could be the opposite.

Finally, it could be discussed, and maybe investigated with simulations, what these attenuation slope differences tell us about galaxy evolution. Do more massive, older galaxies have different dust grains or different dust-stellar geometry than less massive galaxies? Does this difference stem from their past evolution or their current properties? These are difficult questions, but addressing them would greatly improve this line of research.

Interpretation of the Astarte-Adonis pair

Figure 2.1 presents the image of the Astarte-Adonis pair and the total size of the system is 2” $\times$ 1”, which corresponds to 15 kpc $\times$ 7.5 kpc. Could it be that the whole system is a single galaxy with dusty and dust free parts, as found for some submm galaxies? The total size is not exceedingly large for such a massive galaxy.

On the other hand, ALMA detects only a single line for Astarte. This is interpreted as CO(3-2) line, which places the galaxy at the same redshift as derived photometrically and at a similar redshift to that from optical spectroscopy of Adonis. This sounds reasonable, but alternatives of other CO transitions or other lines should be ruled out, both at lower and higher redshift. This can be done for example if the obtained luminosity would be unfeasibly large or that the SED would be incompatible with other redshifts, or that the alternative solution would imply that other lines should be visible. This is especially important given the velocity difference of 1300 km/s, too high for an interacting pair of galaxies only a few kpc away from each other.

Minor comments

I have several minor comments.

- In the second paragraph of section 1.4 the physical interpretation of the mass-metallicity relation is presented. It is stated that metal enrichment can happen through gas accretion from the intergalactic medium. This process works in an opposite way. Gas in the IGM is usually metal-poor, so accretion leads to dilution of metals present in the ISM and a drop in average metallicity.

- Similarly, it is stated there that SN and AGN feedback can expel gas and therefore decrease the metallicity. Galactic winds remove both hydrogen and metals, so do not reduce metallicity, unless some specific geometry of metal-rich clouds is assumed.

- At the end of sections 2.2 and 3.2 the presented section numbers are wrong.

- In section 2.4.1 “Line-integrated flux and luminosity” the size of the CO disk is quoted at 74 kpc. Figure 2.1 shows that it is around 1 arcsec, so it must be 7.4 kpc.
- The spatial offset of 0.39 arcsec between the stellar and CO emission for Astarte (the end of section 2.4.1) is not unexpected. See Rujopakarn et al. (2016) and Dunlop et al. (2017) in which the offsets of similar magnitude are measured and fully explained by astrometric shifts between the coordinate solutions used for optical and long-wavelength data.
- It would be good to repeat the analysis of the attenuation slope, redshift and size (Fig. 11) at the same rest-frame wavelength. Now it is unclear which of the trends are a result of the adopted band tracing different rest-frame wavelength.
- Error estimates are missing for the IRX-β relation in eq. 4.10.
- Figures 3.10 and 4.2 present a conflicting picture on whether it is possible to estimate dust luminosity without far-infrared data. This should be discussed.
- The reference list for the adopted name-year citation style should be sorted alphabetically.

Conclusion

I conclude that this thesis represents a valuable contribution to the field of galaxy evolution and star formation and therefore I recommend granting the doctoral degree to Mahmoud Hamed.

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